NASA's ADVANCED ON-BOARD PROPULSION PROGRAM: ACTIVITIES AT JOHN H. GLENN RESEARCH CENTER

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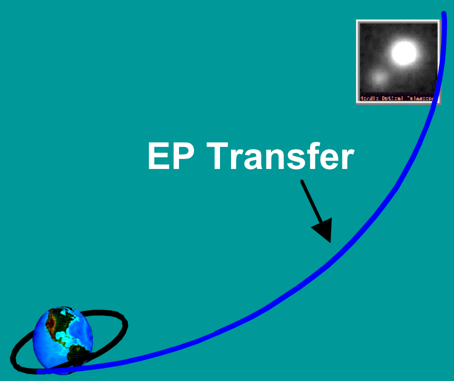
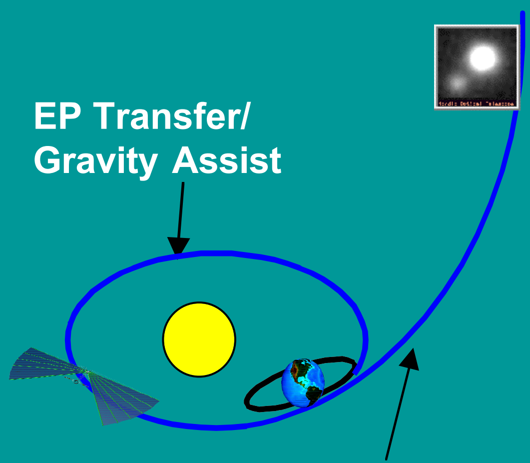
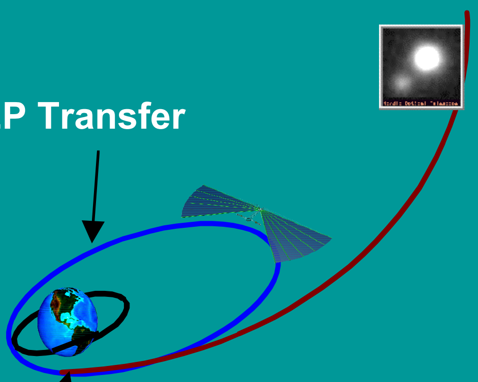
ADVANCED SPACE PROPULSION WORKSHOP

3-5 APRIL 2001
HUNTSVILLE, AL

Electric Propulsion - Candidate Trajectory Approaches







- Low Power Ion Direct
- Launch Vehicle Upper Stage Kicks to High C3 Earth Escape
- Ion Propulsion Used on Direct Trajectory to Pluto, Thrusting Out to Uranus

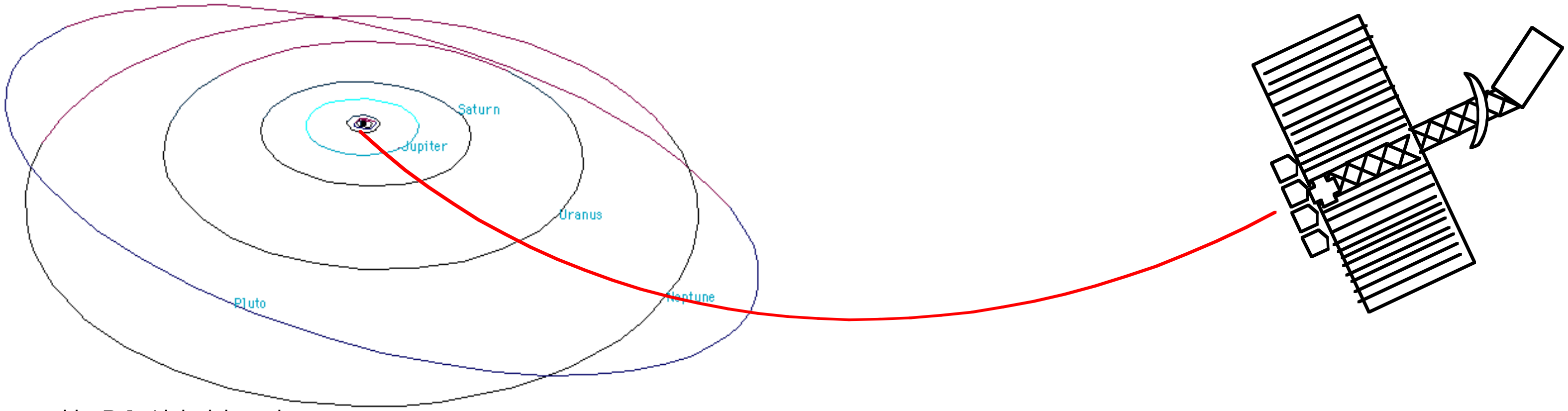
- High Power Ion/Gravity Assists
- Launch Vehicle Upper Stage Kicks to Low C3 Earth Escape
- Ion Propulsion Used During Inner Solar System Cruise
- Gravity Assist at Venus or Earth
- Ion Propulsion Continues Out to Jupiter

- High Power Hall Pump-Up
- Hall Thruster Stage Delivers Spacecraft to Near Earth Escape
- Chemical Propulsion to Inject into direct trajectory to Pluto
- Continued Interplanetary Use of Hall System May Improve Mission

High Power Electric Propulsion Enables Edge of Solar System Probes

- Achieve > 550 a.u. in 10 to 20 years*
- Explore Kuiper belt, Oort Cloud, Heliopause, Deep Space observation…
- High Isp propulsion needed for the High Energy Mission
- Isps 10,000 to 15,000 sec to minimize launch mass
- High PowerElectric Propulsion 0.1 - >1 MW Options
  - Ion
  - MPD
  - PIT
- Use with nuclear power systems
- Similar to nuclear powered crewed planetary exploration vehicles

GRC MW-class MPD Thruster

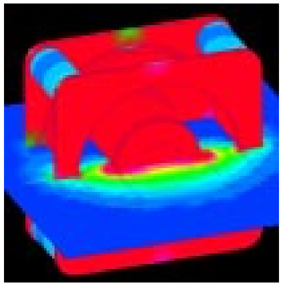


*Proposed by R.J. Lipinsk i, et.al.

Develop a high power Hall propulsion system based on existing design heritage, using mission and engineering constraints as inputs.

Physical Processes & Engineering Constraints

- Performance
- Magnetic System
- Thermal
- Materials
- Stability

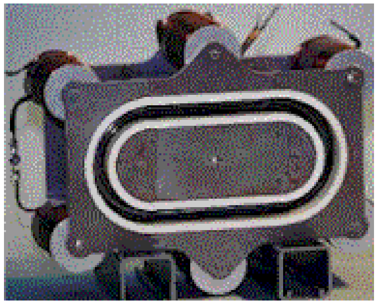


Mission Requirements

- Isp, Thrust, Efficiency
- Throttleability
- Lifetime
- EMI
- Mass

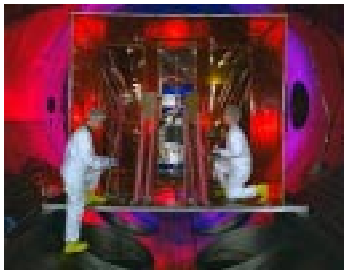
High Power Propulsion System

- SPT vs. TAL vs. Hybrid
- Annular vs. Racetrack Geometry
- Single vs. Clusters vs. Nested

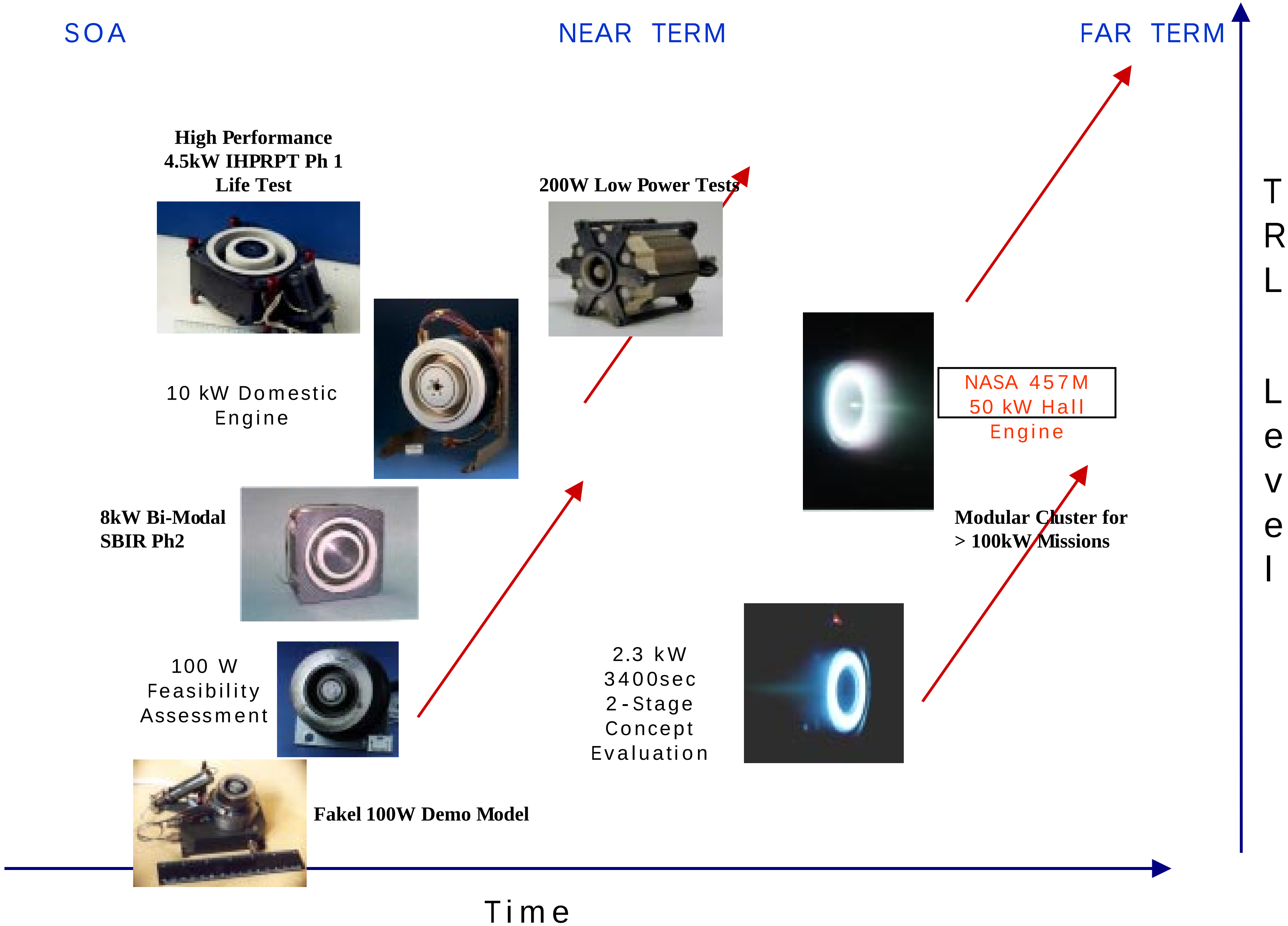


High Power Facility Issues

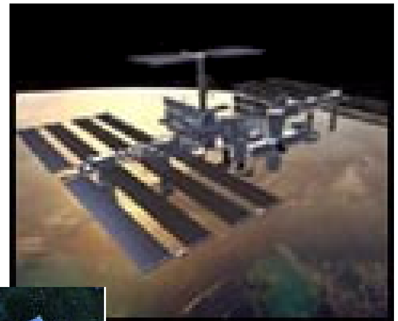
- Thrust Stand
- Pumping Speed
- Chamber Size
- Power & Feed Systems
- Thermal Limitations



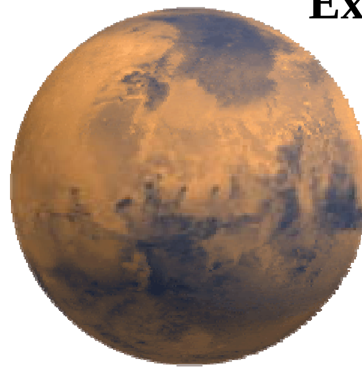
Hall Thruster Roadmap



ISS Drag Makeup
Significantly reduces required refueling flights

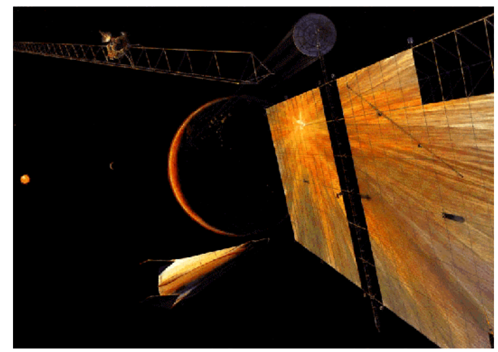


Lunar/Mars Exploration
Eliminates need for nuclear technology, Reduces Launch Vehicle Fleet



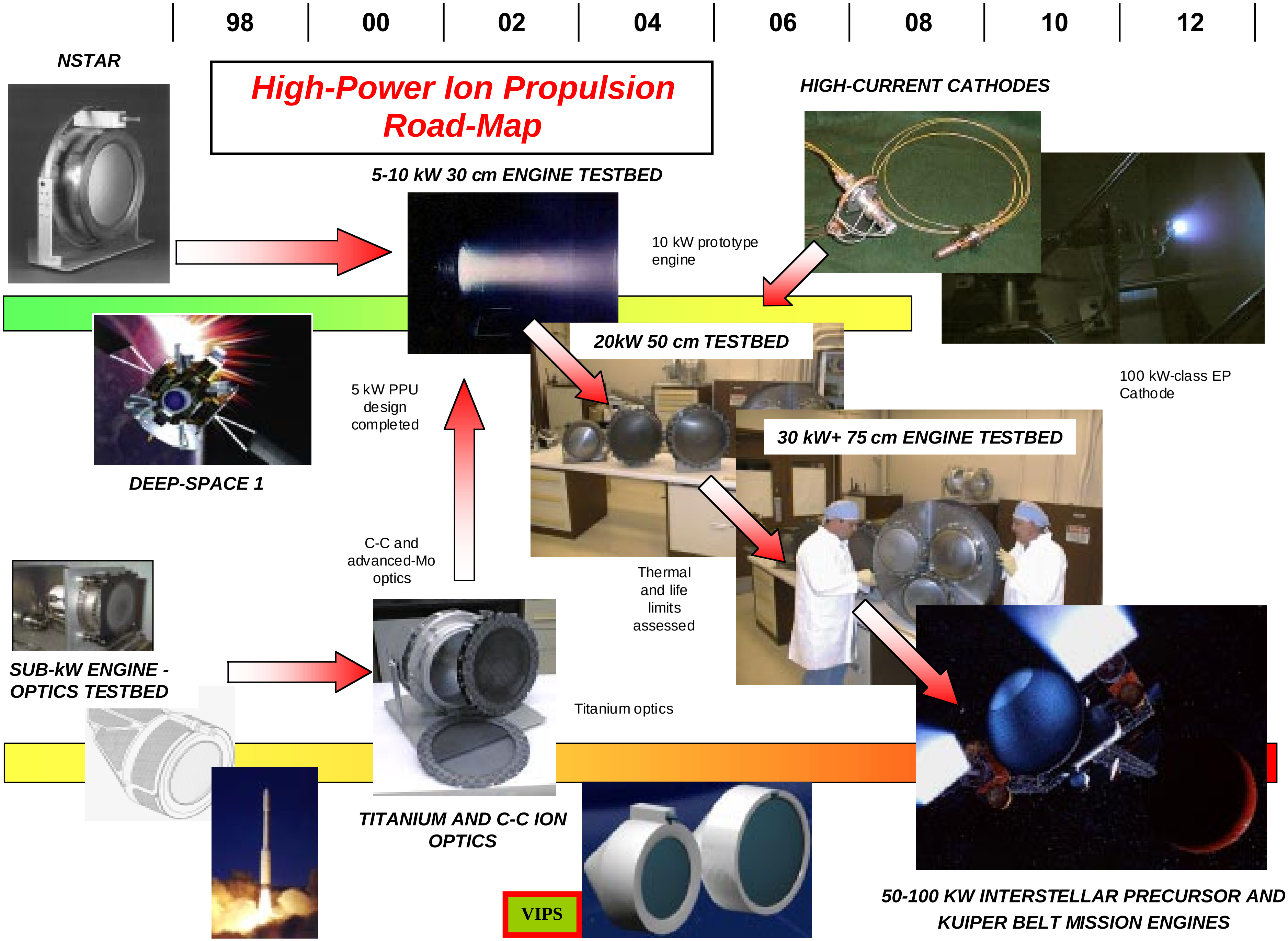
LEO to GEO space transportation *Four Times the Payload of Chemical Systems In Four Weeks using next generation Power levels*

•Need Power Levels ~ 50 kW & Isps ~ 2500 sec



Space Solar Power *Reduces number of launch vehicles required by a factor of 5 ! Deliveries in few weeks to less than four months.*

Hall Propulsion - *50 kW Thruster Applications*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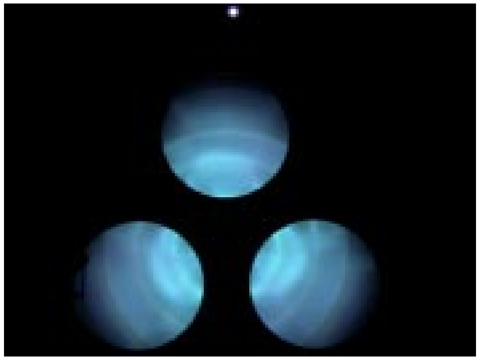
High-Power Ion Propulsion Road-Map
NSTAR
DEEP-SPACE 1
5-10 kW 30 cm ENGINE TESTBED
10 kW prototype engine
HIGH-CURRENT CATHODES
100 kW-class EP Cathode
20kW 50 cm TESTBED
30 kW+ 75 cm ENGINE TESTBED
5 kW PPU design completed
C-C and advanced-Mo optics
Thermal and life limits assessed
SUB-kW ENGINE - OPTICS TESTBED
TITANIUM AND C-C ION OPTICS
Titanium optics
VIPS
50-100 KW INTERSTELLAR PRECURSOR AND KUIPER BELT MISSION ENGINES

- **Major accomplishments:**
  - Design and fabrication of large-area discharge chamber completed.
  - Discharge operation characterized on krypton and xenon propellants.
  - Performance characterized.



- **Near Term Plans (FY01):**
  - Manufacture large-area, high-voltage ion optics.
  - Demonstrate engine operation at > 10,000 seconds Isp.

Ion Propulsion - *Interstellar Precursor Technology*

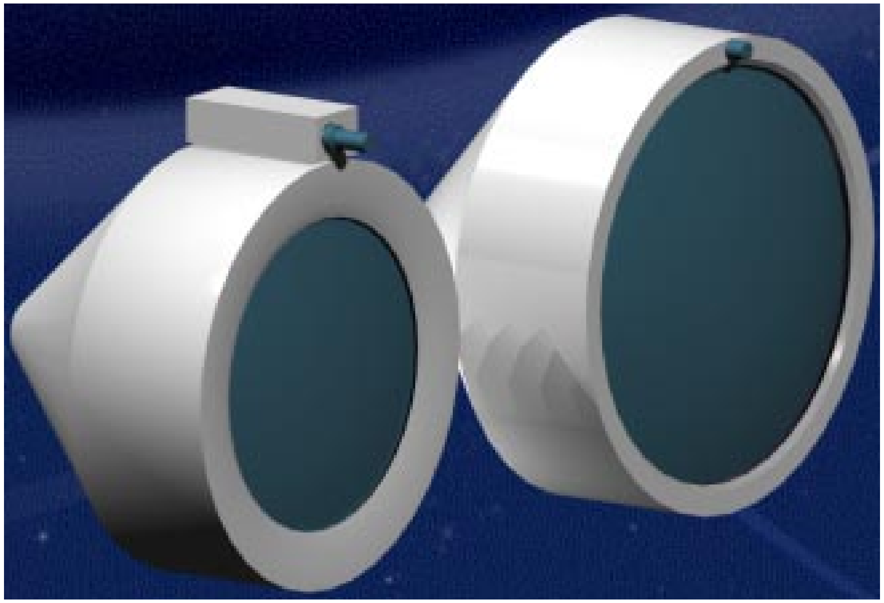
- **Near Term Plans:**

  Conduct design and performance analysis, of next-generation large-area thruster.

  Complete detailed mechanical design of thruster.

  Fabricate and assemble prototype thruster, and conduct preliminary performance testing.

Size comparison of NSTAR and Next-Generation thruster.



Ion Propulsion - *5 kW Next-Generation Ion Technology*

FEASIBILITY OF A HOLLOW-CATHODE-BASED MICRO ION THRUSTER FOR MICROSPACECRAFT

"Micro" Ion Engine Technology

Develop Prototype

RELIES ON HIGH IONIZATION EFFICIENCIES DEMONSTRATED WITH SMALL GRC HIGH ASPECT RATIO HOLLOW CATHODES

GOAL: >25% EFFICIENCY, >1500 S Isp, 5-25 W

00	01	02	03	04	05	06	07	08	09	10	11	12

Sub-kW Ion Propulsion Technology Road-Map options

'12 Option

No Flow Cathode

Thermal and life limits assessed

C-C Optics
30 kg Xe
Throughput

300 W
3300 sec
56% Efficient
30 kg Xe
Throughput

'09 Option

Thermal and life limits assessed

Advanced Moly or Titanium optics
20 kg Xe Throughput

300 W
2800 sec
49% Efficient
20 kg Xe Throughput

'06 Option

0.5 sccm Cathode

Thermal and life limits assessed

Moly optics
12 kg Xe Throughput

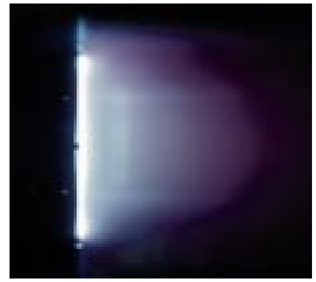
Regulated 28v PPU

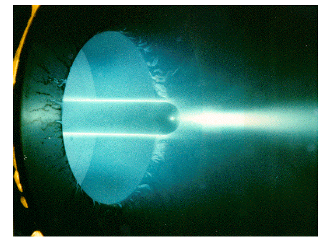
300 W
2800 sec
49% Efficient
12 kg Xe Throughput

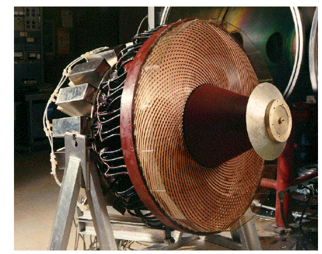
High Power Propulsion

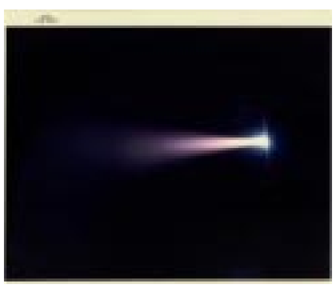
Potential transportation systems include

- **Electric and Plasma Propulsion:**
  - **100 KW LEO to GEO deliver 6000 kg in 60 days**
  - **100 KW powered Interstellar precursor mission, 10 times payload increase**
  - **1 MW Jupiter mission (1 year trip time)**
  - **Multi-MW class fast Human planetary mission (1 year round trip to Mars)**
  - **Options include ion thrusters, Hall thrusters, MPD, Pulsed Inductive Thrusters, and VASMIR**



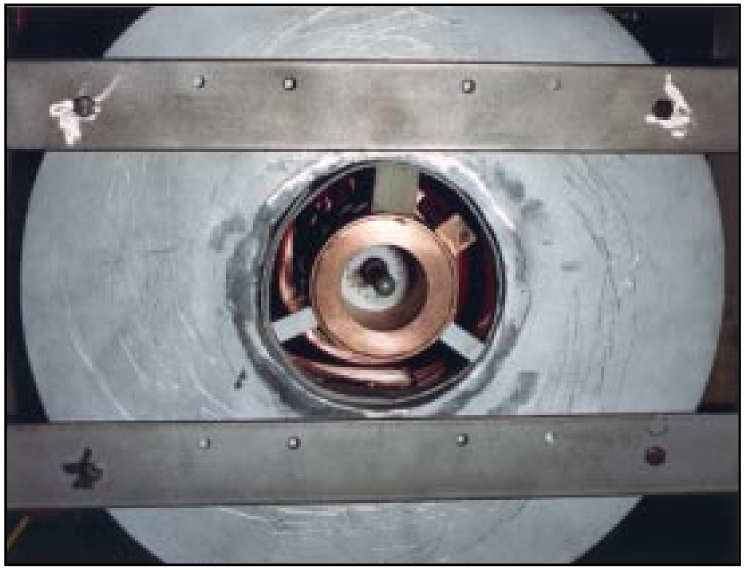






KEY TECHNOLOGIES: Electrode lifetimes, power conditioning, high energy density capacitors, sputter resistant materials, lightweight magnets, magnetic nozzle work, thermal control and propellant management

Magnetoplasmadynamic (MPD) Thrusters



NASA GRC 0.1 MW-Class MPD, Circa 1989

Benefits

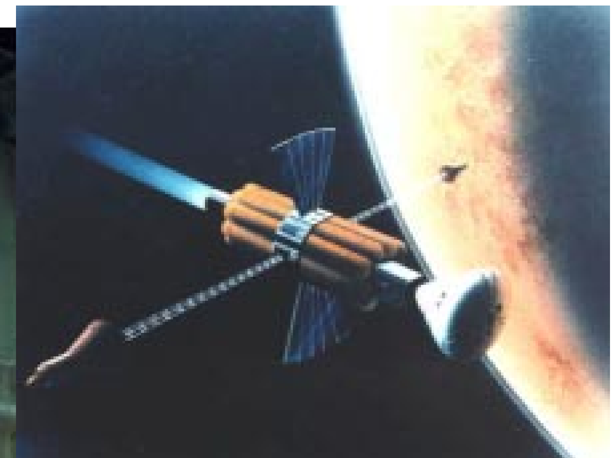
- Robust
  - Simple design and construction; can operate with various propellants.
- High Power Capability with Low Volume Requirements
  - Steady-state devices tested to 500-kW; pulsed devices tested to several MW.
- Potential High Performance
  - 30-kW tests demonstrated 70% efficiency at 5000 s using applied magnetic fields and lithium propellant (Gianinni Scientific Corp., NASA GRC, circa 1968)

NASA GRC 0.1 MW Steady-State Helium MPD, Circa 1989

Challenges

- Thruster Lifetime
  - Electrode erosion at high currents.
- MW-Class Operation
  - Address high power thermal design issues, improve thruster efficiencies
  - Power management and distribution
  - Propellant handling

MPD THRUSTER PROGRAM PLANS



FY01-02 — **FY03-05** — **FY06**

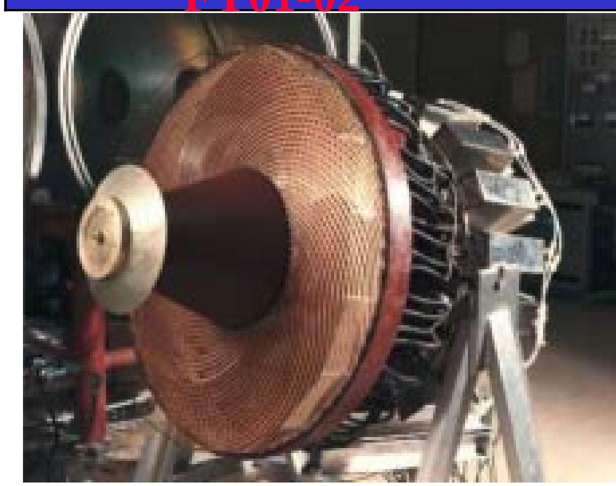
FY01-02	FY03-05	FY06
USE NUMERICAL MODELING AND PULSED MW-CLASS MPD THRUSTER EXPERIMENTS TO ESTABLISH EFFICIENT MPD THRUSTER DESIGNS	TRANSITION EFFICIENT DESIGNS TO MW-CLASS, STEADY-STATE FACILITY; EVALUATE MPD THRUSTER LIFETIME AND EFFICIENCY	ENGINEERING MODEL MPD THRUSTER: • 50% EFFICIENCY • 5000 HOURS LIFE • 2,500 s - 7,000 s Isp

PULSED INDUCTIVE THRUSTER PROGRAM PLANS

NUMERICAL MODELING AND FABRICATION OF MULTIPLE REP-RATE PIT DESIGN (GRC/TRW/MSFC)

SINGLE-SHOT AND MULTIPLE REP-RATE EVALUATION OF PIT PERFORMANCE

FY01-02 FY03-04 FY05-06 >FY06

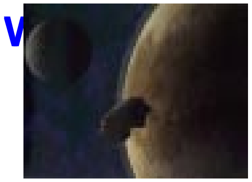


SOLID STATE SWITCH DEVELOPMENT AND INTEGRATION INTO MULTIPLE REP-RATE THRUSTER

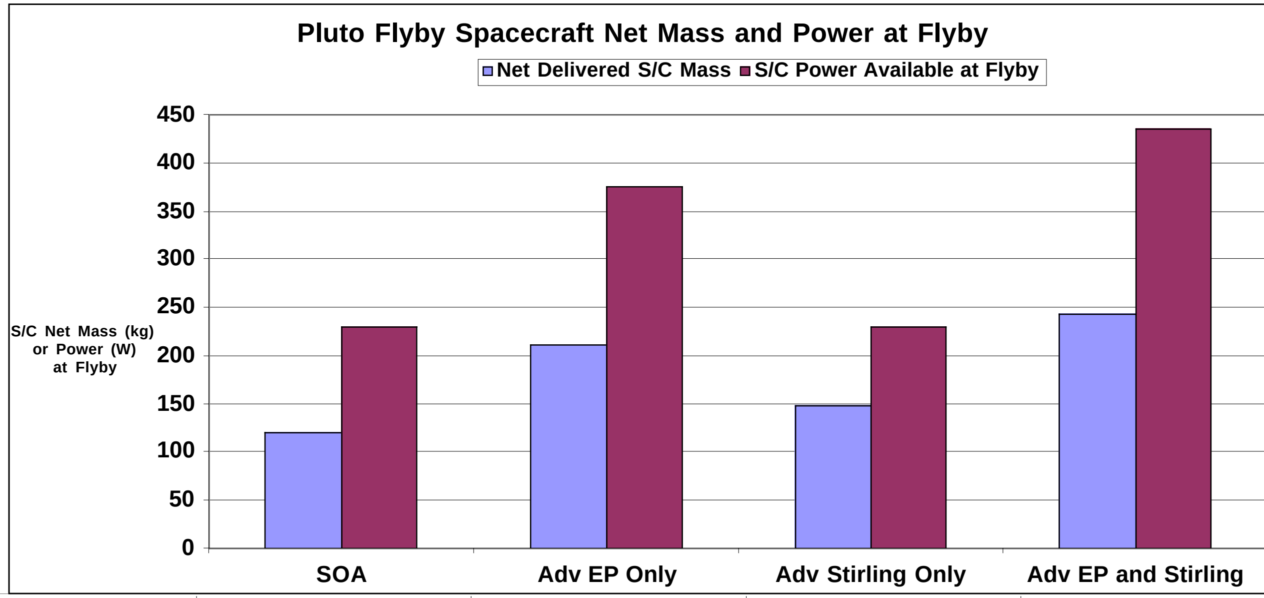
ENGINEERING MODEL PIT THRUSTER:

- **60% EFFICIENCY**
- **HIGH REP-RATE**
- **2,500 s - 7,500 s Isp**

Combined Benefits of Propulsion and Pow
for Pluto Flyby (

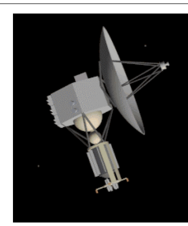


- **Radioisotope Electric Propulsion**
- **Add Electric Propulsion to increase Payload**
- **No launch window constraints, direct, fast trajectories**
- **Stirling Converter Reduces required # of P_u Modules**
- **Combination of Ion thrusters and Stirling Converters:**
- **Doubles Useable S/C Payload and Power at Flyby**



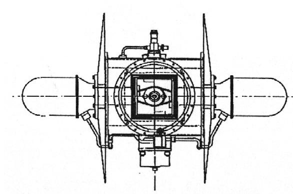
	SOA	Adv EP Only	Adv Stirling Only	Adv EP and Stirling
Power (BOM)	290 W	474 W	250 W	474 W
Power (Flyby)	230 W	376 W	230 W	435 W
EP Propellant		84 kg		84 kg
Power mass	56 kg	92 kg	29 kg	60 kg
Propulsion mass		29 kg		29 kg
Net S/C Mass	121 kg	212 kg	148 kg	243 kg
# of Pu Modules	2 7	4 3	6	1 0

All Cases:
Atlas IIIb//Star48V
2009 Launch
2020 flyby



Direct RTG

Electric Prop- 8cm Ion thrusters



Radioisotope with Stirling Converters

Electric Propulsion and Stirling Radioisotope Converters